



Technical Memorandum

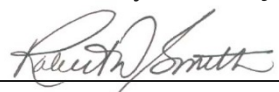
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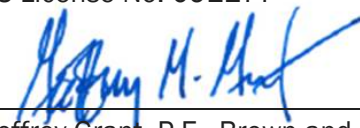
Technical Memorandum

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List of Abbreviations

AACE	Association for the Advancement of Cost Engineering	EPA	United States Environmental Protection Agency
BWT	Bureau of Wastewater Treatment	HGL	hydraulic grade line
CEQR	New York City Environmental Quality Review	LF	linear feet
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act	MG	million gallon(s)
CSO	combined sewer overflow	mgd	million gallon(s) per day
DEC	New York State Department of Environmental Conservation	MHW	mean high water
DEP	New York City Department of Environmental Protection	OH	Owls Head
DSNY	New York City Department of Sanitation	PRPs	potentially responsible parties
El.	Elevation	PS	pumping station
		RD	Remedial Design
		RH	Red Hook
		ROD	record of decision
		WWTP	Wastewater Treatment Plant

Executive Summary

This Tunnel Evaluation Summary Technical Memorandum summarizes the analyses completed to assess the viability of a tunnel as an alternative to the Gowanus CSO storage facilities which are required to comply with the requirements identified in the EPA's Record of Decision (ROD), May 2014 Administrative Order for Remedial Design, June 2016 Settlement Agreement, and Statement of Work.

As summarized in this Memorandum, the New York City Department of Environmental Protection (DEP) has studied whether alternatives to constructing two CSO tanks could meet EPA Superfund requirements and yield benefits beyond those provided by CSO tanks to the environment and the community. DEP has concluded that a tunnel alternative would, at a comparable cost to the CSO tanks, meet or exceed Superfund requirements, provide additional CSO control, help improve neighborhood drainage, and reduce flooding. Critically, and unlike CSO tanks, a tunnel would allow for future scalable and integrated infrastructure improvements to ensure resiliency benefits and facilitate further CSO capture. Additionally, a tunnel design would allow for the preservation of 234 Butler Street and tunnel construction would be less disruptive than tank construction since much of the work involves underground tunneling. Accordingly, DEP recommends pivoting to a tunnel solution as the most cost-effective, beneficial and sustainable project to meet EPA's requirements while providing additional benefits for the surrounding community.

Specifically, DEP recommends pivoting to Option 3a: Tunnel with Flood Benefits. Option 3a would provide CSO controls that exceed the requirements of the ROD and relieve flooding in a flood-prone neighborhood. Moreover, because Option 3a is scalable, DEP could decide at a later time to build out additional infrastructure that would provide additional resiliency, flood control and CSO control benefits in the future.

Introduction

On March 2, 2010, the United States Environmental Protection Agency (EPA) added the Gowanus Canal Superfund Site to the Superfund Program's National Priorities List on and the City of New York was named as one of several potentially responsible parties (PRPs). In September 2013, EPA, acting under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, also known as Superfund), issued its (ROD) describing the selected remedy for the Gowanus Canal Superfund Site, including CSO sediments controls.

In May 2014, EPA issued an Administrative Order for Remedial Design (Index Number CERCLA-02-2014-2019) (RD UAO) to the City of New York (City) that contained a Statement of Work (SOW) specifying tasks to design the components of the remedy selected in the ROD for control of combined sewer overflow (CSO) discharges and restoration of the 1st Street Turning Basin. The City was directed to institute CSO controls consisting of retention tanks to intercept discharges from the two largest CSO discharges to the Gowanus Canal, outfall RH-034 in the Red Hook (RH) Wastewater Treatment Plant (WWTP) drainage area and outfall OH-007 in the Owls Head (OH) WWTP drainage area.

In June 2016, EPA and the City entered into an Administrative Settlement Agreement and Order for Remedial Design, Removal Action and Cost Recovery (Index Number CERCLA-02-2016-2003) (Settlement Agreement) which supersedes the RD UAO for the RH-034 CSO facility and includes schedule milestones for completing the Environmental Impact Statement, property acquisition, design submittals, and site preparation and demolition activities, and a Removal Action. The OH-007 CSO remains subject to the RD UAO.

EPA determined that construction of an 8-million-gallon (MG) tank at RH-034 and a 4 MG tank at OH-007 would enable the City to achieve a 58 to 74 percent reduction of CSO solids discharged to the

Gowanus Canal at each of the outfalls respectively. EPA's economic analysis estimated cost for both tanks of \$ 77 million, which is far below typical facility costs for construction of similar infrastructure, especially in New York City.

Currently, the construction of tank facilities for RH-034 and OH-007 is estimated to cost a total of \$1.2 billion (including construction, approximately \$90 million in land acquisition, design, and construction management) and construction is estimated to be completed in September 2028. DEP, as the City agency responsible for implementing the CSO control-related tasks required in the Settlement Agreement and RD UAO, has investigated whether there are alternative options which would achieve EPA's control requirements along with co-benefits not provided by CSO tanks – specifically flood and surcharge relief in a part of the City that has long experienced wastewater and stormwater conveyance issues.

Purpose of Gowanus Tunnel Evaluation

Subsequent to its initiation of the remedial design of storage tanks for RH-034 and OH-007, DEP initiated a parallel study to assess the feasibility of constructing a tunnel solution as an alternate to the tanks to address the Gowanus Superfund requirements with the following objectives:

- At a minimum, evaluate a tunnel size and alignment that meets the ROD requirement of 12 MG of total storage for the RH-034 and OH-007 outfalls.
- Identify possible synergistic benefits that a tunnel provides including:
 - Increased environmental benefit such as capturing CSO from additional outfalls to the canal, thereby further reducing the number of overflow events
 - Flood Reduction Benefits
 - Resiliency Benefits
- Identify possible phasing of CSO controls that could be added in the future. Scalability and adaptability to address other drainage issues in adjacent areas where the tunnel alignment and depth could provide for future additional facilities for storm surge protection in Red Hook.

Evaluation Approach

The scope of the tunnel evaluation included 5 components that helped to identify viable alternatives:

1. **System Characterization:** Detailed modeling of the combined sewer system to identify and quantify conveyance issues in the local area – including locations of model predicted surcharge and flooding (under a DEP 5-yr/2-hr storm event) that could be addressed with a tunnel solution. Model predicted hydraulic grade lines (HGL), flow rates, and storage volumes needed to alleviate the issue(s) were used to size the conceptual tunnels and to identify drop shaft locations which optimized hydraulic benefits to the drainage area and informed the alignment of the tunnel alternatives.
2. **Operational Requirements:** Identification of mechanical and operational components of a tunnel system, as identified through a survey of other CSO tunnel systems. Key tunnel components identified through the survey were reviewed with representatives from DEP's Bureau of Wastewater Treatment (BWT) which is charged with operating DEP's wastewater infrastructure, including CSO facilities, to confirm the conceptual layouts and configurations were consistent with their operational needs. During these workshops, preferences for mechanical screening equipment, pump station (PS) configuration, and drop shaft configuration were determined. The outcome of the analysis was used as the basis of design for conceptual layouts and cost estimating.

3. **Tunnel System:** Based on the findings from Components 1 and 2, potential tunnel alignments that connected the problem areas were developed – considering both horizontal and vertical alignments. The vertical alignment endeavored to avoid conflicts with the non-aqueous phase liquid (NAPL) barrier wall project, other potential pile supported structures, and mixed face conditions while the horizontal alignment endeavored to avoid the permanent acquisition of private property by using the canal and public right-of-ways for the tunnel alignment.
4. **Cost Estimate and Schedule:** Association for the Advancement of Cost Engineering (AACE) Class IV cost estimates were developed for the viable tunnel alternatives. Construction and program schedules were developed to compare the differences between a tank and tunnel solution in complying with the ROD, RD UAO and Settlement Agreement requirements.
5. **Summary:** Preparation of reports and workshops to summarize the outcomes of the analysis.

Tunnel Alternatives

The analysis identified three areas of concern in the collection system around the Gowanus canal that could be addressed by a tunnel solution:

- **Flooding and surcharge:** Located in several sewers, most notably along 4th Avenue, near the bottom of Park Slope.
- **Resiliency:** Reduced ability to discharge combined sewer overflow from existing outfalls assuming a future increase in sea level
- **Bond Lorraine:** Restrictions in the Bond Lorraine sewer and Red Hook interceptor that create hydraulic grade concerns that cannot easily be resolved with conventional cut and cover solutions.

Based on these three problem areas, a series of tunnel alternatives were identified and are summarized below.

Options for ROD Compliance and Possible Synergistic Benefits

Option 1: Storage Tanks

Option 1 includes two separate CSO storage tank facilities at RH-034 and OH-007 that DEP is currently obligated to design under the Settlement Agreement and RD UAO. A 4-MG storage facility is planned for OH and an 8 MG facility is planned for RH, providing a total of 12 MG of CSO storage volume. The preferred site for an RH-034 facility is the RH-3 Head End Property (also known as the Canal Side Property); however, DEP is also advancing a parallel design for the RH-4 Park Property if the RH-3 Site cannot be acquired. The location of the proposed storage tanks is shown on Figure ES-1. Option 1 establishes a base level of service for a Gowanus CSO storage facility and will be used as basis of comparison for tunnel alternatives.

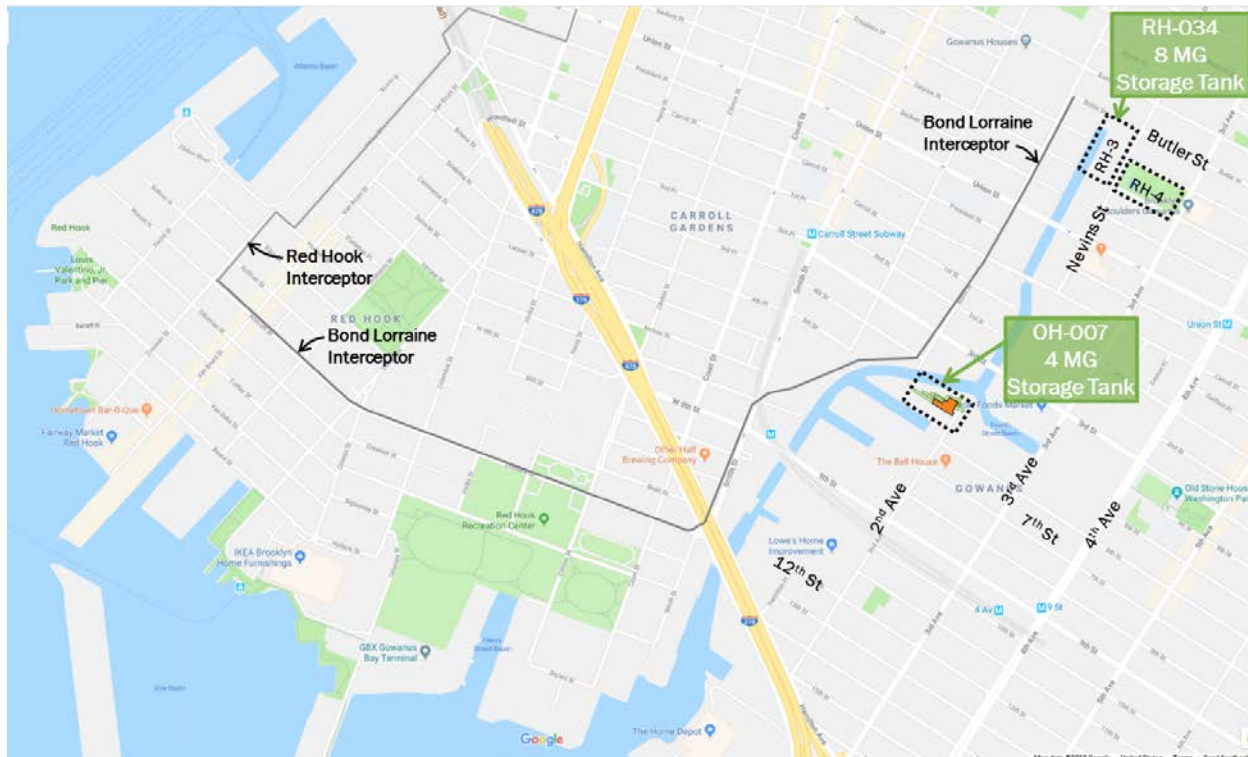


Figure 1. Option 1: Storage Tanks

The RH storage tank will provide storage for flows from the RH-034 regulator and flow will be diverted to the facility via a new influent channel that ties into the eastern wall of the existing regulator structure. The RH-033 outfall will be demolished and weirs will be raised upstream of RH-036, RH-037, and RH-038 to divert flow to RH-034. The RH facility will be sized to convey the typical year peak flow rate of 323 mgd. Bending weirs will be installed along the influent conveyance channel to provide hydraulic relief if inflows exceed the typical year peak flow of 323 mgd and allow excess flows to discharge to the Canal.

The OH storage facility will provide storage for flows normally discharging through the OH-007 outfall. A new diversion structure and influent channel will be installed upstream of the existing OH-007 outfall and silt trap basin to divert flows to the facility. The existing silt trap basin and OH-007 outfall will be abandoned after the new storage facility is completed. The OH facility will be sized to convey the typical year peak flow rate of 146 mgd and excess flows will be allowed to overflow to the Canal via a new outfall.

Storage tanks are designed to be flow-through to provide primary settling and will overflow to the canal once storage capacity is exceeded. Current tank designs also include fine screening and continuous pumping of inflows through grit classifiers to provide additional floatables and grit capture. CSO capture and solids reduction performance associated with Option 1 is Table 1.

Table 1. CSO Typical Year (2008) Performance with Option 1

Storage Volume (MG)	Total Project Cost (billion)	CSO Performance							
		Percent Capture		Annual Average Overflows (MG)		Number of Activations		Percent Solids Removal	
		RH-034	OH-007	RH-034	OH-007	RH-034	OH-007	RH-034	OH-007
12	\$1.117	75.4%	84.6%	30.9	9.7	6	4	85%	99%

Option 1a: Tanks with Flood Reduction Benefits (13.5 MG)

Option 1a adds 1.5 MG storage in microtunnels in 12th Street, 2nd Avenue, and 7th Street to the tanks in Option 1. The main features of Option 1a include:

- 12 MG Storage Tanks to satisfy EPA's Record of Decision requirements (same as Option 1)
- Approximately 4,200 feet of 96-inch microtunnels
- Diversion structures at 7th Street/4th Avenue and 12th Street/3rd Avenue with overflow weirs set 18 inches below the crown of the existing sewers
- Expanded outfall structure at CSO OH-007

The microtunnels lower the HGL within these sewers to below street level during a DEP five-year, two-hour storm. The location of the proposed storage tanks and microtunnels alignment is shown on Figure 2.

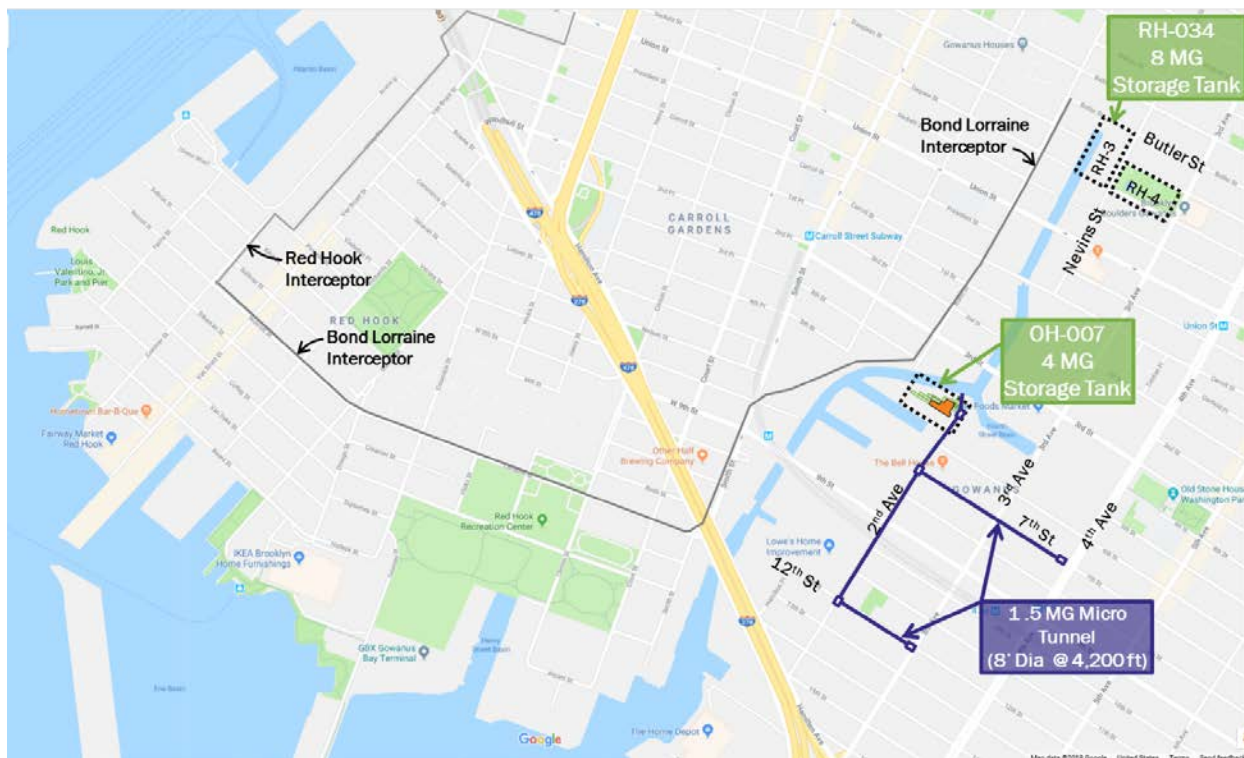


Figure 2. Option 1a: Tanks with Flood Reduction Benefits (13.5 MG)

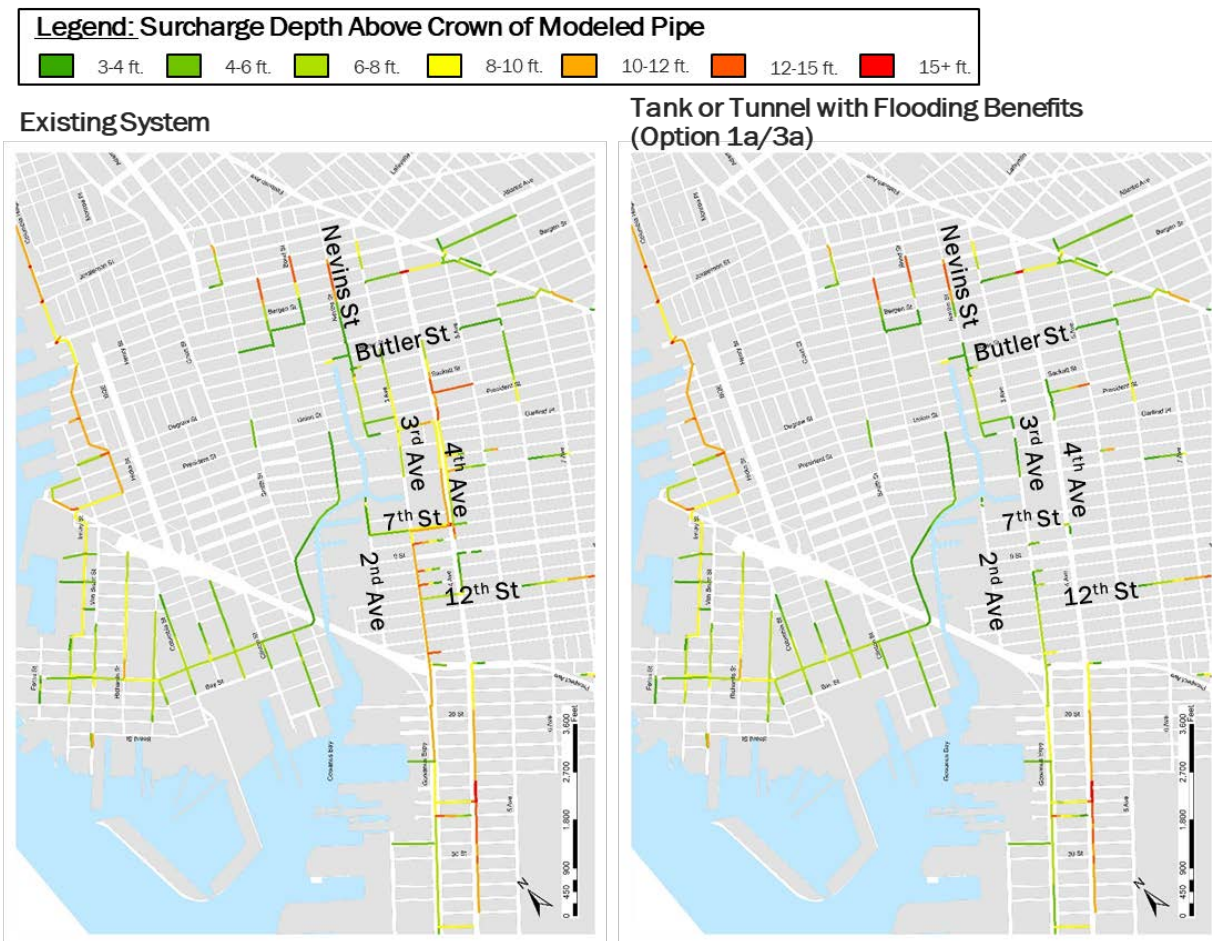
During large storms, flows that exceed the downstream trunk sewer capacity pass over the side overflow weirs and enter the microtunnels, reducing the HGL upstream of the diversion structures. Since there are no other connections to the microtunnels between the diversion structures and outfall at OH-007, the microtunnel could be slightly pressurized (surcharged) without impacting the hydraulics of the collection system. The microtunnels could also be dual purposed to provide additional CSO capture by allowing the microtunnel to be backfilled after the OH-007 storage tank reaches capacity, which has the benefit of reducing overflows from OH-007.

An expanded outfall structure with additional bending weirs and tide gates reduce surcharging and maximizes flood control. The Option 1a performance is shown in Table 2.

Table 2. CSO Typical Year (2008) Performance with Option 1a

Storage Volume (MG)	Total Project Cost (billion)	CSO Performance							
		Percent Capture		Annual Average Overflows (MG)		Number of Activations		Percent Solids Removal	
		RH-034	OH-007	RH-034	OH-007	RH-034	OH-007	RH-034	OH-007
13.5	\$1.422	75.4%	85.3%	30.9	9.3	6	4	85%	99%

The sewer surcharge reduction benefits of Option 1a compared to the existing conditions for the 5-Year DEP Storm are shown on Figure 3. The model is showing surcharging to street level along 4th Avenue under existing conditions, which is controlled with Option 1a improvements. Surcharging is also reduced along 3rd Avenue, 7th Street, and 12th Street with the Option 1a improvements.

**Figure 3. Sewer Surcharge Reduction Benefits of Option 1a**

Option 2: Tunnel with Equivalent ROD Storage Volume (12 MG)

In lieu of separate storage facilities, Option 2 constructs a common 12 MG storage tunnel with drop shafts at OH-007 and RH-034 to meet the combined storage requirement established in the ROD. Option 2 includes approximately 2,600 linear feet (LF) of 24-foot inner diameter tunnel which provides additional storage in drop shafts up to Elevation (El.) -1.57 feet NAVD88. The conceptual tunnel alignment developed for Option 2a is shown on Figure 4.

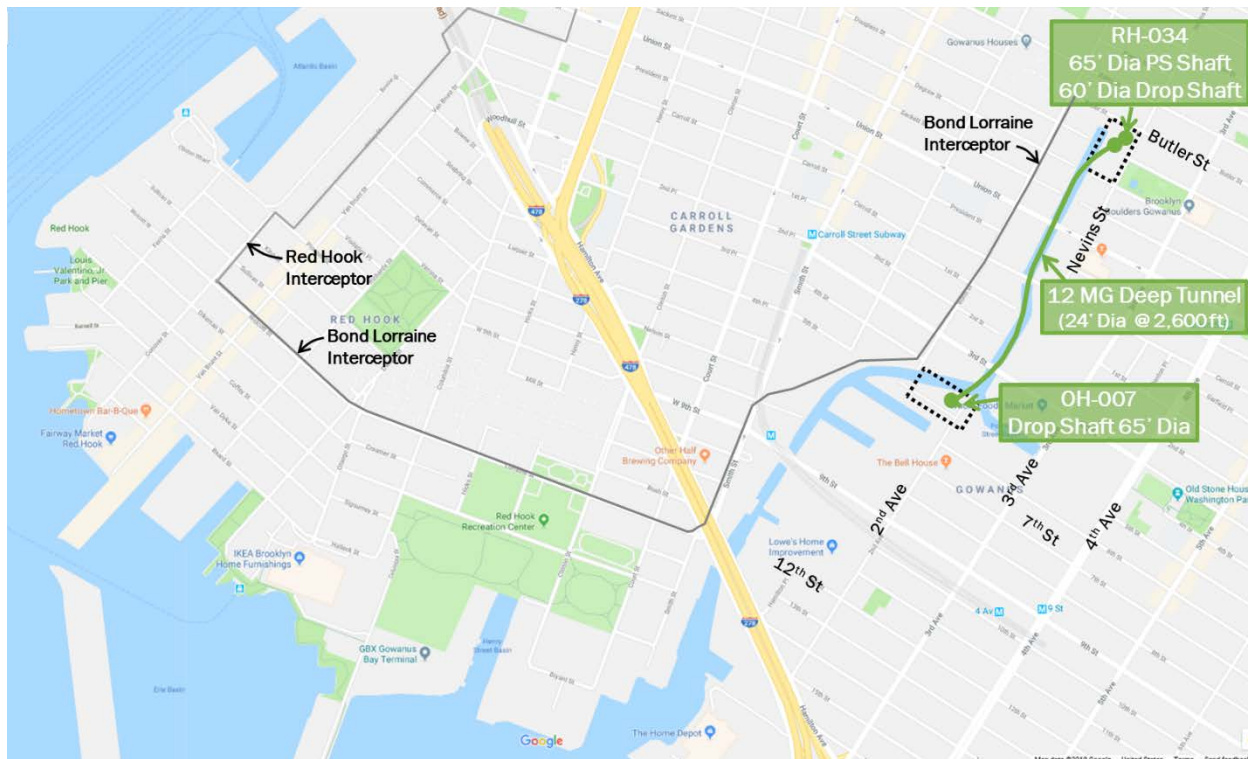


Figure 4. Option 2: Tunnel with Equivalent ROD Storage Volume (12 MG)

Diversion structures and conveyance conduits will be similar to the tanks design to convey flows to drop shafts at OH-007 and RH-034. Flows will be diverted to the RH-034 drop shaft via a new conduit connecting to the eastern side of the existing RH-034 regulator. Flows will be diverted to an OH-007 drop shaft from a new diversion structure and influent conduit installed upstream of the existing OH-007 outfall. Drop shafts and conveyance conduits will be sized to convey 323 mgd and 146 mgd at RH-034 and OH-007, respectively. CSO capture and solids reduction performance associated with Option 2 is shown in Table 3.

Table 3. CSO Typical Year (2008) Performance with Option 2

Storage Volume (MG)	Total Project Cost (billion)	CSO Performance							
		Percent Capture		Annual Average Overflows (MG)		Number of Activations		Percent Solids Removal	
		RH-034	OH-007	RH-034	OH-007	RH-034	OH-007	RH-034	OH-007
12	\$1.204	68.3%	100%	39.7	0	6	0	68.4%	100%

Option 3: Equivalent Solids Removal Tunnel (16 MG)

Unlike a storage tank, a CSO storage tunnel is not assumed to provide flow-through treatment of CSO flows diverted to the facility. Once the tunnel reaches its storage capacity, CSO is diverted to a passive relief outfall and would not undergo screening, settling, or grit removal. Option 3 constructs a 16 MG storage tunnel with drop shafts at OH-007 and RH-034 that would provide equivalent solids capture to the current storage tanks design. Option 3 includes approximately 2,600 LF of 28-foot inner diameter tunnel, which provides additional storage in drop shafts up to El. -1.57 feet NAVD88. Option 3 is shown on Figure 5 and follows the same alignment as Option 2. Option 3 also includes the same diversion structures and conveyance conduits as Option 2. CSO capture and solids reduction performance associated with Option 3 is Table 4.

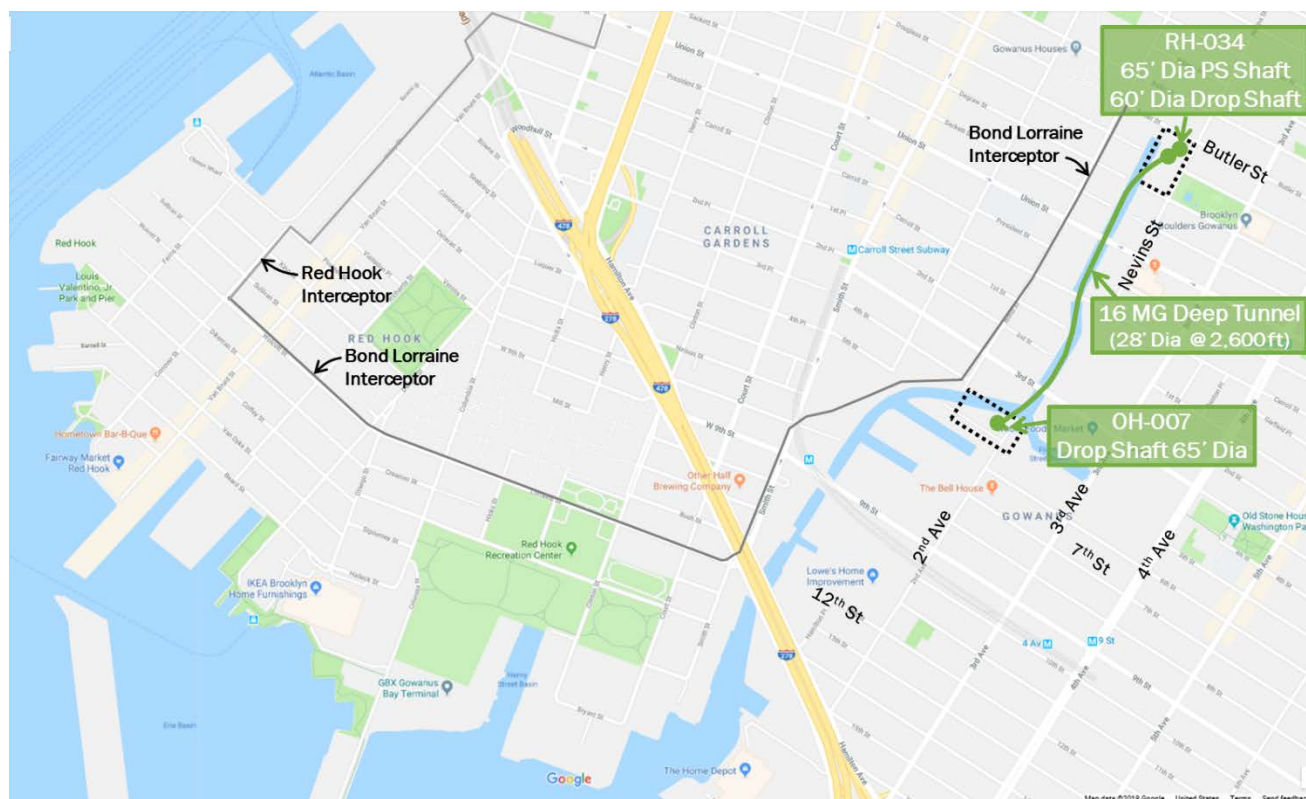


Figure 5. Option 3: Equivalent Solids Reduction Tunnel (16 MG)

Table 4. CSO Typical Year (2008) Performance with Option 3

Storage Volume (MG)	Total Project Cost (billion)	CSO Performance							
		Percent Capture		Annual Average Overflows (MG)		Number of Activations		Percent Solids Removal	
		RH-034	OH-007	RH-034	OH-007	RH-034	OH-007	RH-034	OH-007
16	\$1.231	82.5%	100%	21.9	0	4	0	82.5%	100%

Option 3a: Tunnel with Flood Reduction Benefits (17.5 MG)

Option 3a adds microtunnels in 12th Street, 2nd Avenue, and 7th Street to the 16 MG tunnel in Option 3. The main features of Option 3a include:

- 16 MG storage tunnel to satisfy EPA's Record of Decision requirements (same as Option 3)
- Approximately 4,200 feet of 96-inch microtunnels
- Diversion structures at 7th Street/4th Avenue and 12th Street/3rd Avenue with overflow weirs set 18 inches below the crown of the existing sewers.
- Expanded outfall structure at CSO OH-007.

Microtunnels HGL within these sewers to below street level during a DEP five-year, two-hour storm with same results as Option 1a. The location of the proposed storage tunnel and microtunnels alignment is shown on Figure 6.

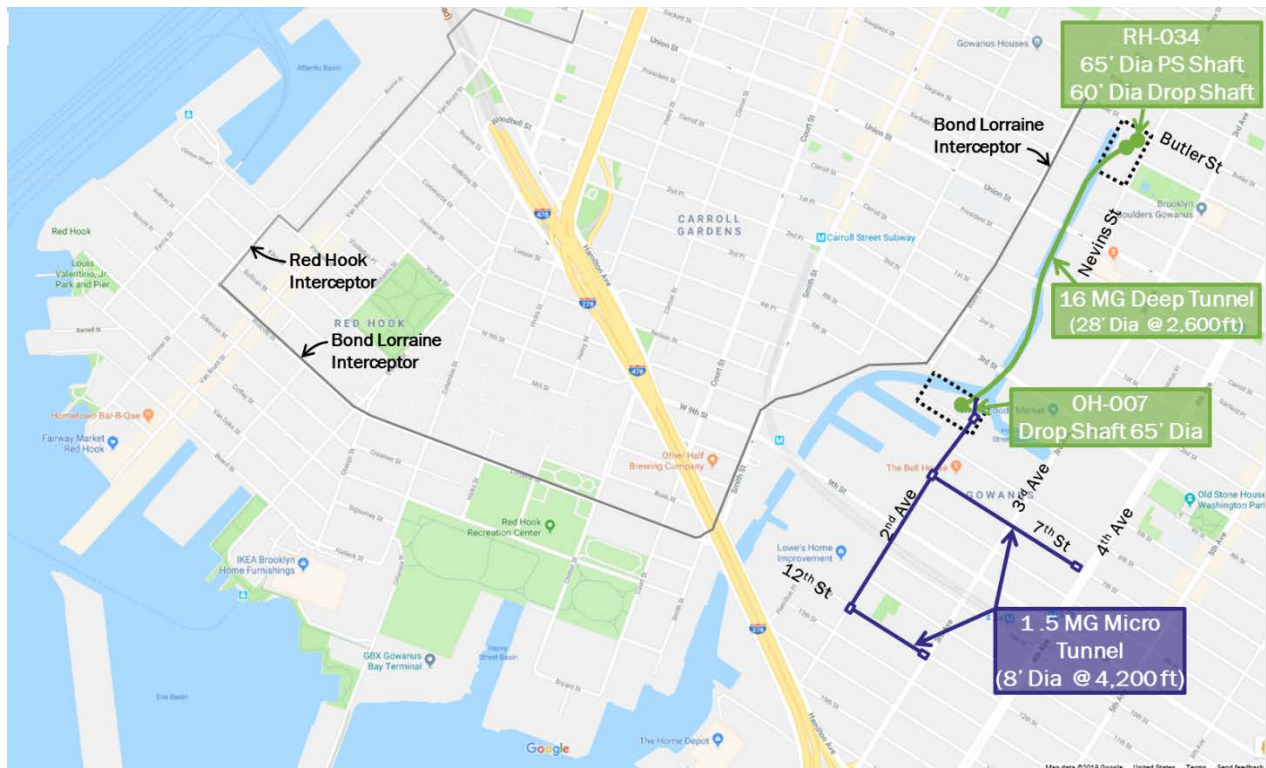


Figure 6. Option 3a: Tunnel with Flood Reduction Benefits

The Option 3a microtunnels in 7th Street, 12th Street, and 2nd Avenue will operate in the exact same manner as the Option 1a microtunnels. See Option 1a (above) for a description of the hydraulic operation of the microtunnels. The Option 3a performance is shown in Table 5, which is comparable to the performance of Option 1a.

Table 5. CSO Typical Year (2008) Performance with Option 3a

Storage Volume (MG)	Total Project Cost (billion)	CSO Performance							
		Percent Capture		Annual Average Overflows (MG)		Number of Activations		Percent Solids Removal	
		RH-034	OH-007	RH-034	OH-007	RH-034	OH-007	RH-034	OH-007
17.5	\$1.424	83%	100%	21.3	0	4	0	83%	100%

Sewer surcharge benefits of the Option 3a are shown compared to the existing conditions for the 5-Year DEP Storm on Figure 7.



Figure 7. Sewer Surcharge Reduction Benefits of Option 3a

Option 3b: Tunnel with Flood Reduction and Resiliency Benefits (25.4 MG tunnel, 1.5 MG microtunnel, 26.9 MG total storage)

Based on the April 21, 2017 Mayor's Office of Recovery and Resiliency Preliminary Climate Resiliency Design Guidelines, sea level may rise by as much as 58 inches by the year 2080 and negatively impact the HGL and conveyance capacity of sewers influenced due to tidal backwater conditions. One solution to handle the effects of sea level rise is to fully capture of the DEP 5-year, 2-hour storm. To provide full capture of the DEP 5-year, 2-hour storm at RH-034, OH-007, and diversions at 7th Street and 12th Street, the tunnel and microtunnels would need to provide approximately 26.9 MG of total storage.

Option 3b includes the construction of a 26.9 MG storage tunnel system extending south along 2nd Ave beyond the OH-007 site to a New York City Department of Sanitation (DSNY) property on 2nd Avenue between 11th and 12th Streets. Beyond the OH-007 site, the tunnel alignment follows the 2nd Avenue right-of-way. The total length of the Option 3b tunnel alignment is approximately 4,670 LF with a tunnel inner diameter of 28 feet. Shafts are included at RH-034, OH-007, and the DSNY property at 12th Street/2nd Avenue. Because the OH-007 drop shaft cannot be constructed in-line with the tunnel without requiring an easement for the tunnel alignment, a deep adit (short hand-mined tunnel) will be constructed to convey flows from the shaft to the tunnel. 96-inch microtunnel diversion sewers are also included to convey flows from 7th Street/4th Avenue and 12th Street/3rd Avenue to the OH-007 drop shaft. Microtunnels provide an additional 1.5 MG of in line storage volume. The conceptual tunnel alignment developed for Option 3b is shown on Figure 8.

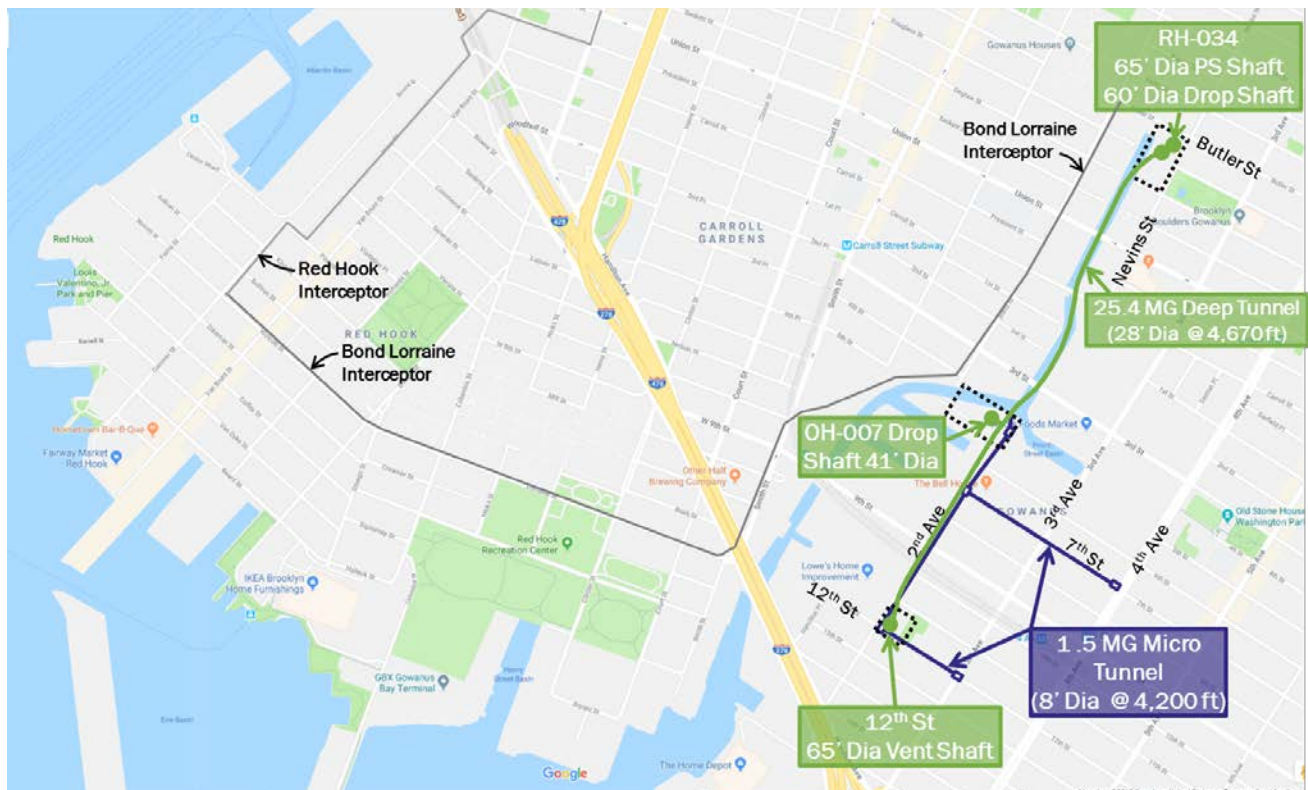


Figure 8. Option 3b: Tunnel with Flood Reduction and Resiliency Benefits (26.9 MG)

The Option 3b microtunnels in 7th Street, 12th Street, and 2nd Avenue will operate in the exact same manner as the Option 1a and Option 3a microtunnels and provide comparable flood reduction benefits. See Option 1a (above) for a description of the hydraulic operation of the microtunnels. The Option 3b performance is shown in Table 6.

Table 6. CSO Typical Year (2008) Performance with Option 3b

Storage Volume (MG)	Total Project Cost (billion)	CSO Performance							
		Percent Capture		Annual Average Overflows (MG)		Number of Activations		Percent Solids Removal	
		RH-034	OH-007	RH-034	OH-007	RH-034	OH-007	RH-034	OH-007
26.9	\$1.718	99.5%	100%	0.6	0	1	0	99.5%	100%

The sea level rise resiliency benefits before and after the Option 3b improvements for the 5-Year DEP Storm with 58 inches of sea level rise are shown on Figure 9. Option 3b provides full capture of the 5-Year DEP Storm, removing the tidal influence on sewers upstream of the tunnel and microtunnel drop shafts. This benefits sewers along 3rd Avenue, 4th Avenue, 7th Street, and 12th Street as well as in the Boerum Hill area served by RH-034.

Legend:

 Tidally Influenced Sewers for 5-Year DEP Storm at MHW + 58" SLR

Existing System**Tunnel with Flooding & Resiliency Benefits (Option 3b)**

Figure 9. Resiliency Benefits of Option 3b

Option 4a: Tunnel with Flood Reduction Benefits with Bond Lorraine (27.5 MG)

The Bond Lorraine sewer conveys flows from the Gowanus area to the Red Hook Interceptor. Excess flows in the Bond Lorraine sewer are relieved by three regulated CSO outfalls along its length from Douglass & Bond Streets to its connection to the Red Hook Interceptor at Wolcott & Conover Streets. The Bond Lorraine Sewer has a very shallow slope. This shallow slope, coupled with deep invert elevations (below present day tidal levels), leaves the Bond Lorraine sewer prone to sedimentation and flooding. Flooding and significant surcharge between 3 to 7 feet is predicated across the entire segment. To successfully achieve a hydraulic benefit across the entire length of the Bond Lorraine using an overflow weir to a tunnel, several modifications would be required as follows:

- Install a bulkhead or check valve on the Bond Lorraine to hydraulically disconnect Bond Lorraine sewer from the Red Hook interceptor.
- Add a 5.2 mgd pumping station to convey up to twice the dry weather flow from the Bond Lorraine sewer to the Red Hook interceptor.
- Connect the Bond Lorraine sewer to the Gowanus Tunnel at CSO regulators RH-035, RH-031, and RH-030 to control wet weather flows greater than the capacity of the Bond Lorraine dry weather PS.

Option 4a includes a 25-MG storage tunnel that follows Gowanus Canal and includes microtunnels in Owls Head (same as Option 3a) as well as microtunnels in Red Hook that provide an additional 2.5 MG. Option 4a is shown on Figure 10.

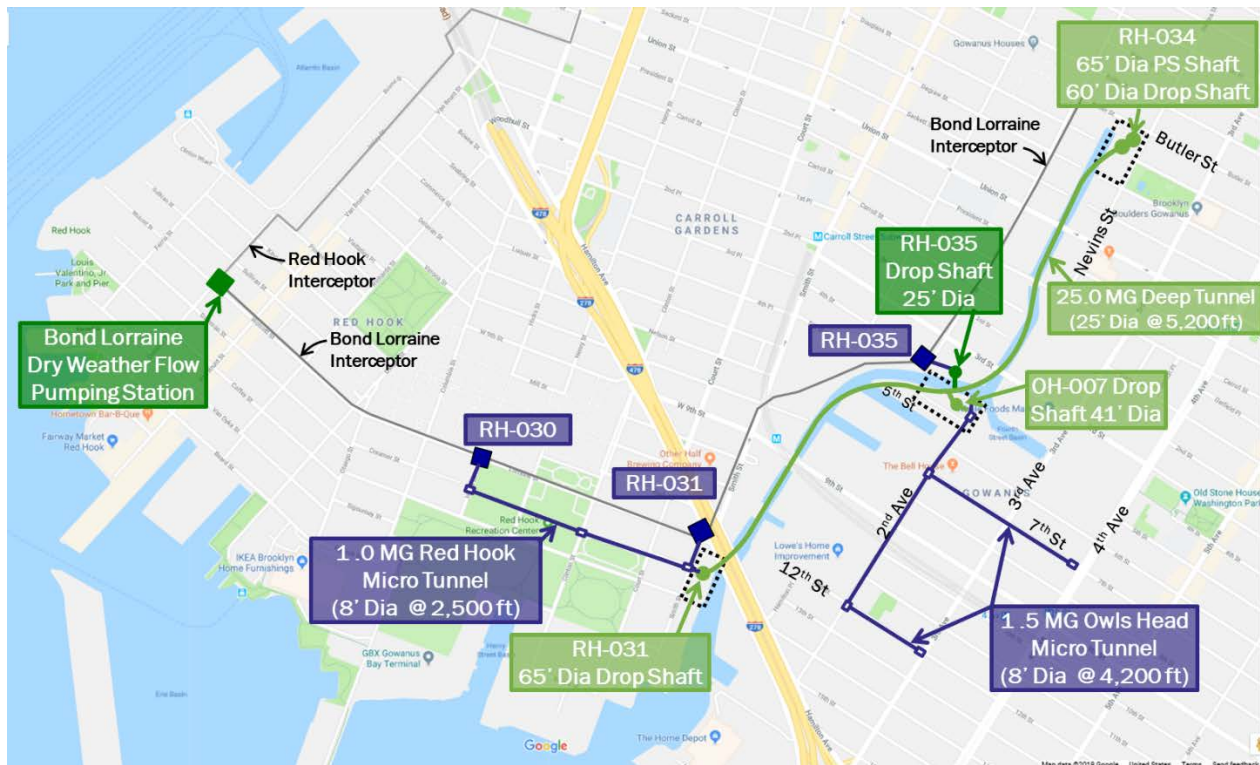


Figure 10. Option 4a: Tunnel with Flood Reduction Benefits with Bond Lorraine (27.5 MG)

The total length of the Option 4a tunnel alignment is approximately 5,200 linear feet with an inner diameter of 25 feet. Drop shafts are included at RH-034, OH-007, RH-035 and a property south of the Gowanus Parkway near outfall RH-031. The OH-007 and RH-035 drop shafts would include a deep adit to convey flows from the shaft to the deep tunnel. The Option 4a Owls Head microtunnels will operate in the exact same manner as the Option 1a. The Red Hook microtunnels convey flows to the

drop shaft at RH-031, which would include an expanded outfall at RH-031. Further evaluation is required to determine the optimum hydraulic operation of the Red Hook microtunnel. The Option 4a performance is shown in Table 7.

Table 7. CSO Typical Year (2008) Performance with Option 4a									
Storage Volume (MG)	Total Project Cost (billion)	CSO Performance							
		Percent Capture		Annual Average Overflows (MG)		Number of Activations		Percent Solids Removal	
		RH-034	OH-007	RH-034	OH-007	RH-034	OH-007	RH-034	OH-007
27.5	\$2.100	73.7%	99.8%	33	0.1	4	2	73.7%	99.8%

Model results indicate that creating a tunnel discharge at regulators RH-030, RH-031, and RH-035 along the Bond Lorraine sewer would decrease the HGL by 5 to 6 feet and reduce flooding along the length of the sewer for the 5-Year DEP Storm. Option 4a also provides flooding benefits in the Park Slope area, including along 3rd Avenue, 7th Street, and 12th Street, comparable to Option 1a and 3a. These results are shown on Figure 11. Further evaluation is required to validate the solution identified within the Bond Lorraine sewer and possible synergies with a Gowanus Tunnel options.

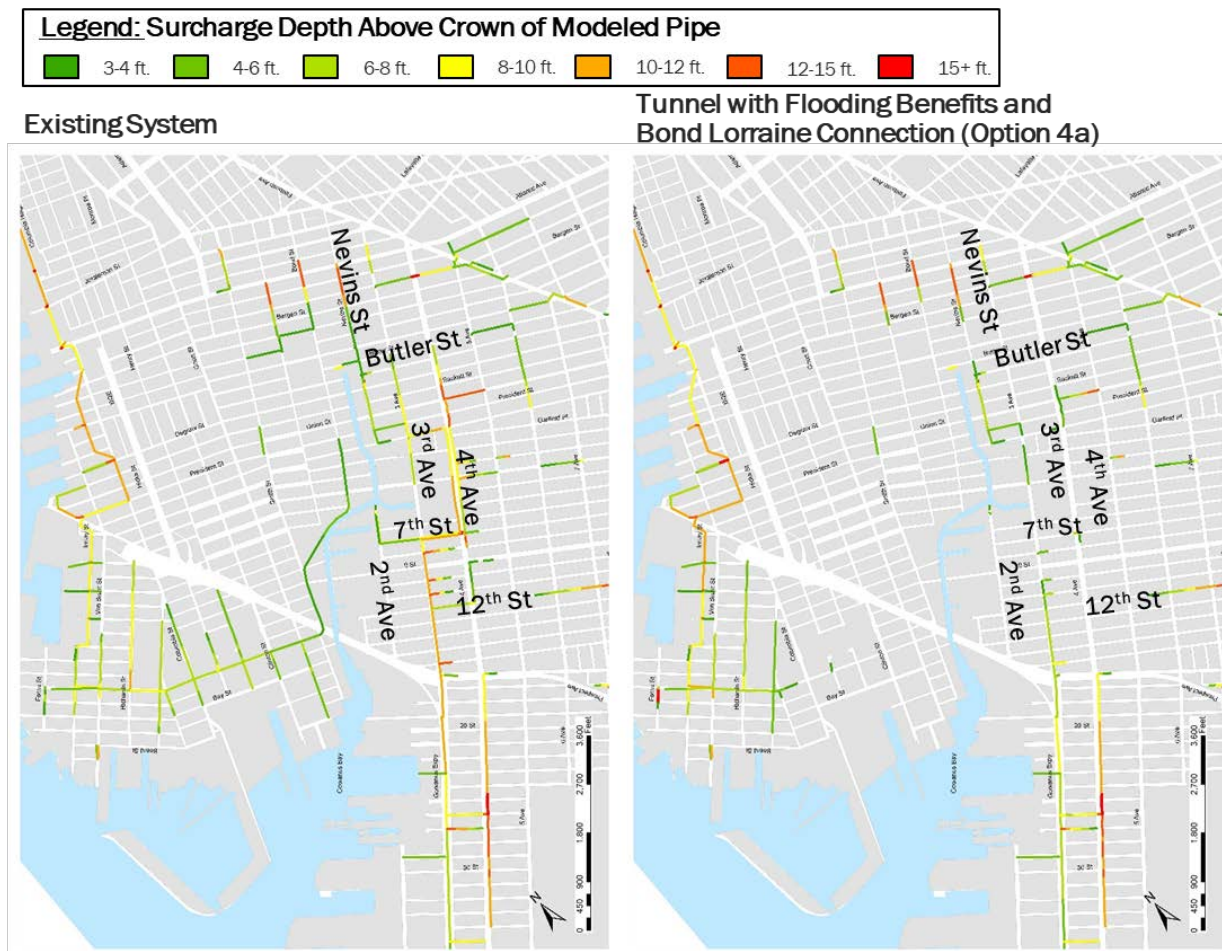


Figure 11. Sewer Surcharge Reduction Benefits of Option 4a

Option 4b: Tunnel with Flood Reduction and Resiliency Benefits with Bond Lorraine (37.3 MG)

Issues in the Bond Lorraine sewer were predicted to worsen with projected sea level rise due to the low invert elevation of the sewer. The modeled HGL along the Bond Lorraine was determined to increase proportionally to increases in the modeled MHW under sea level rise conditions, resulting in a 3 to 6-foot increase in the peak HGL for most of the trunk segments. One solution to handle the effects of sea level rise is to fully capture of the DEP 5-year, 2-hour storm. To provide full capture of the DEP 5-year, 2-hour storm at RH-034, OH-007, and CSO outfalls along Bond Lorraine, the tunnel system would need to provide approximately 37.3 MG of storage. The conceptual tunnel alignment developed for Option 4b is shown on Figure 12, which follows the same alignment as Option 4a.



Figure 12. Option 4b: Tunnel with Flood Reduction and Resiliency Benefits with Bond Lorraine (37.3 MG)

The total length of the Option 4b tunnel alignment is approximately 5,200 LF with an inner diameter of 31 feet. Drop shafts would be located at the same locations as Option 4a. The microtunnels in Option 4b would follow the same alignments as Option 4a. The Option 4b microtunnels will operate in the exact same manner as the Option 4a microtunnels and provide comparable flooding benefits to Park Slope and Carroll Gardens along the Bond Lorraine sewer. The Option 4b performance is shown in Table 8.

Table 8. CSO Typical Year (2008) Performance with Option 4b

Storage Volume (MG)	Total Project Cost (billion)	CSO Performance							
		Percent Capture		Annual Average Overflows (MG)		Number of Activations		Percent Solids Removal	
		RH-034	OH-007	RH-034	OH-007	RH-034	OH-007	RH-034	OH-007
37.3	\$2.200	93.4%	100%	8.2	0.02	2	1	93.4%	100%

The sea level rise resiliency benefits before and after the Option 4b improvements for the 5-Year DEP Storm with 58 inches of sea level rise are shown on Figure 13. Option 4b provides full capture of the

5-Year DEP Storm, removing the tidal influence on sewers upstream of the tunnel and microtunnel drop shafts. This benefits sewers along 3rd Avenue, 4th Avenue, 7th Street, 12th Street, and in the Boerum Hill area, served by RH-034, and the Carroll Gardens area, served by the Bond Lorraine sewer.

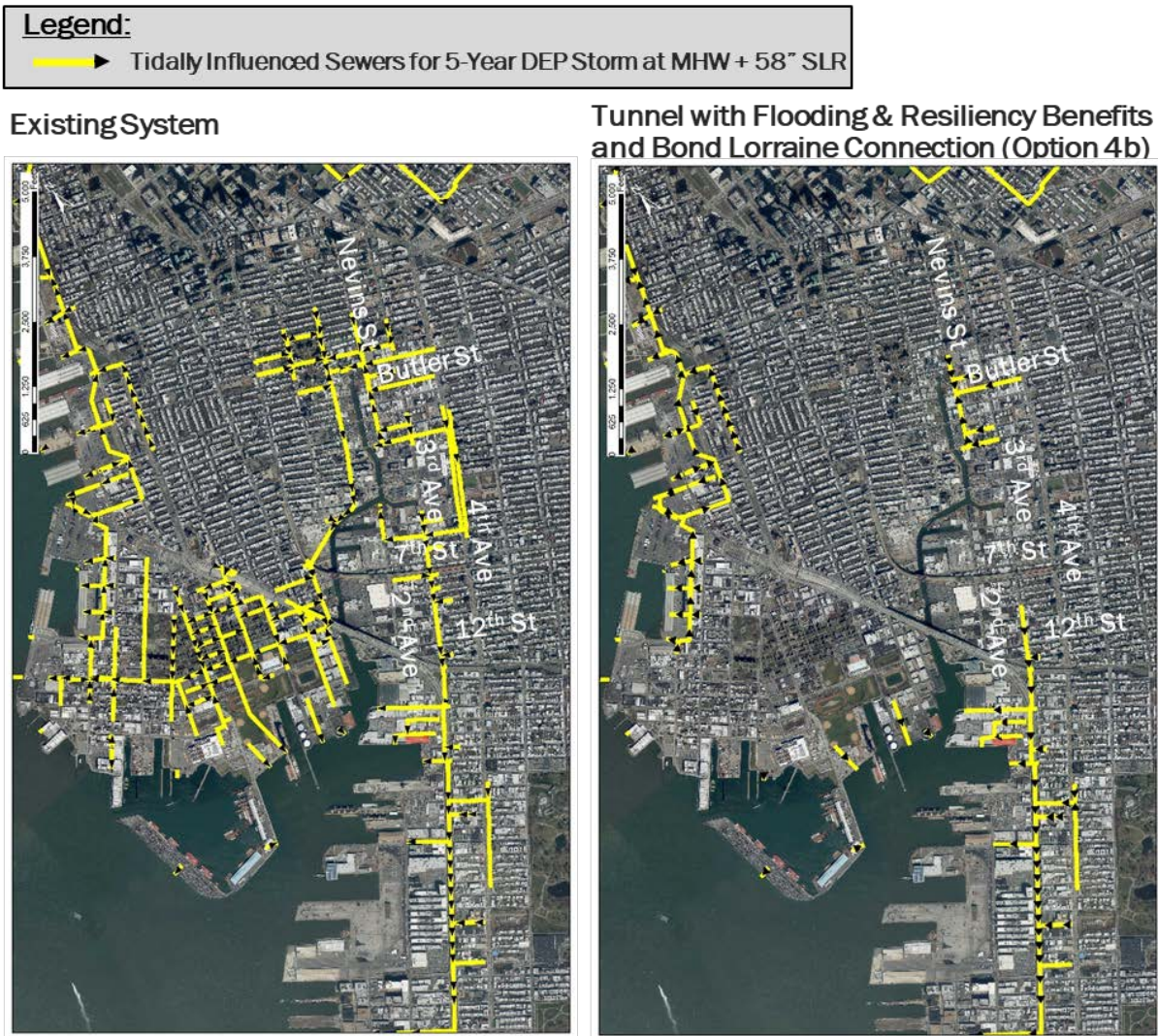


Figure 13. Resiliency Benefits of Option 4b

Further evaluations are required to validate the solution identified within the Bond Lorraine sewer and possible synergies with a Gowanus Tunnel option. Bond Lorraine sewer tunnel connections should be further explored as a future addition or second phase to the scalable base tunnel alignment. As part of this analysis, the required additional tunnel storage volume, optimal tunnel connection locations, dry weather flow PS capacity and location, and the second phase tunnel extension alignment/deep tunnel adit alignment would need to be determined.

Summary of Performance and Cost

The performance of tunnel alternatives was measured against current typical year (2008) CSO outfall activations and overflow volume. Calendar year 2008 was defined as the typical year as part of DEP's CSO Long Term Control Plan. The tunnel alternatives were also compared against anticipated solids load reductions to confirm that the tunnel option would achieve the 58 percent to 74 percent reduction at each of the outfalls required by the ROD, assuming that tunnels do not provide flow-through solids

removal. The typical year performance for all the options is shown in Table 9. Table 9 also shows the facility sizing and costs for each option. The interpretation of the results is provided following Table 9.

Record of Decision Compliance

As indicated in the introduction, the purpose of the Gowanus Canal CSO improvements is to reduce solids loading to Gowanus Canal from CSO overflows. All options identified comply with volume and solids reduction requirements of EPA's Record of Decision. Options 3, 3a, 3b, 4a, and 4b removes the greatest volume from the Gowanus Canal.

Increased Environmental Benefits

Based on the Long Term Control Plan (LTCP) approved by the New York State Department of Environmental Conservation (NYSDEC) in 2017 and implemented by DEP, the Gowanus Canal is in compliance with current NYSDEC dissolved oxygen and bacteria water quality standards. Pursuant to the LTCP and other initiatives, DEP has implemented several projects which have reduced CSO discharges to the Canal, including the Gowanus Pumping Station Upgrades, reactivation of the Gowanus Canal Flushing Tunnel, High Level Storm Sewers, and Green Infrastructure projects. DEP continues to consider additional measures that will further reduce CSO discharges and improve water quality. Therefore, opportunities to provide cost-effective CSO controls or install adaptable CSO facilities should be considered in near and long-term planning. Options 4a and 4b includes a longer tunnel, which provides the opportunity to phase additional CSO controls to achieve even greater environmental benefits (i.e., reduce solids deposition and bacteria discharges, and increase dissolved oxygen by reducing CSO annual volumes).

Hydraulic Benefits and Surge Reduction

Each of the options were modeled for the 5-year DEP design storm under present day MHW conditions to determine their incremental hydraulic benefits to the Gowanus Canal sewershed. New diversion structures at 7th Street and 12th Street provide hydraulic benefits to the sewers upstream, particularly along 4th Avenue. Options 1a, 3a, 3b, 4a, and 4b are predicted to provide flooding and sewer surcharge benefits on the Park Slope side of the canal as far upstream as the 7/4/3 Trunk, which extends to Butler Street. A tunnel would complement the benefits provided by the Carroll Street project and reduce the risk of sewer backups and flooding in an area targeted for future development. Options 4a and 4b provide additional surcharge reduction for the Bond Lorraine sewershed on the western side of the canal. The flood reduction benefit connections are sized to convey and store the flows and volumes associated with the 5-Year DEP storm. The Gowanus Study Area sewers were generally sized to accommodate a 3-Year DEP design storm. If portions of the sewershed are ever upsized per the revised drainage plan criteria, sewers will need a downstream outlet capable of accepting the 5-year DEP storm flows. Therefore, the options that provide flooding benefits also facilitate future sewer replacement by providing a 5-year outlet. Option 4a and 4b provide surcharge relief for the Carroll Gardens area, served by the Bond Lorraine sewer.

Table 9. Summary of Typical Year (2008) Performance

Components	Tank Options		Tunnel Alternatives					
	Option 1: Tanks Only	Option 1a: Tanks with Flood Benefit	Option 2: Equivalent ROD Volume Tunnel	Option 3: Equivalent Solids Removal Tunnel	Option 3a: Tunnel with Flooding Benefits	Option 3b: Tunnel with Flooding and Resiliency Benefits	Option 4a: Tunnel Flooding Benefits with Bond Lorraine	Option 4b: Tunnel Flooding and Resiliency Benefits with Bond Lorraine
Dimensions & Storage Volume								
Deep Tunnel Diameter (ft)	-	-	24'	28'	28'	28'	25'	31'
Deep Tunnel Length (ft)	-	-	2,600	2,600	2,600	4,670	5,200	5,200
Storage Tank or Deep Tunnel Storage (MG)	12	12	12	16	16	25.4	25	34.8
Microtunnel Storage (MG)	-	1.5	-	-	1.5	1.5	2.5	2.5
Total Storage Volume (MG)	12	13.5	12	16	17.5	26.9	27.5	37.3
Cost (\$Billion) (Increase over Option 1)	\$ 1.18	\$ 1.42 (+240 M)	\$ 1.20 (+20 M)	\$ 1.23 (+50 M)	\$ 1.42 (+240 M)	\$ 1.72 (+540 M)	\$ 2.10 (+920 M)	\$ 2.20 (+1,020 M)
CSO Performance								
a. % CSO Captured at RH-034 and OH-007								
RH-034	75.4%	75.4%	68.3%	82.5%	83.0%	99.5%	73.7%	93.4%
RH-034 % Reduction Over Option 1	-	0%	-7.0%	7.1%	7.6%	24.1%	-1.6%	18.0%
OH-007	84.6%	85.3%	100.0%	100.0%	100.0%	100.0%	99.8%	100.0%
OH-007 % Reduction Over Option 1	-	0.7%	15.4%	15.4%	15.4%	15.4%	15.2%	15.4%
b. Annual Average Overflows (MG)								
RH-034	30.9	30.9	39.7	21.9	21.3	0.6	33.0	8.2
OH-007	9.7	9.3	0.0	0.0	0.0	0.0	0.1	0.02
Other Overflows	110.0	110.2	108.4	108.5	108.2	108.4	57.0	56.8
c. Number of Activations								
RH-034	6	6	6	4	4	1	4	2
OH-007	4	4	0	0	0	0	2	1
d. % Solids Removal*								
RH-034	85%	85%	68.4%	82.5%	83.0%	99.5%	73.7%	93.4%
RH-034 % Reduction Over Option 1	-	0%	-16.6%	-2.5%	-2.0%	14.5%	-11.3%	8.4%
OH-007	99%	99%	100%	100%	100%	100.0%	99.8%	100.0%
OH-007 % Reduction Over Option 1	-	0%	1.0%	1.0%	1.0%	1.0%	0.8%	1.0%

*Solids removal in tunnels is based upon volume of capture only. No flow-through treatment was assumed.

Resiliency Benefits

Each of the options were modeled for the 5-year DEP design storm under future mean high water (MHW) with 58-inches of sea level rise to determine the resiliency benefits to the Gowanus Canal area. The Option 3b and 4b tunnel configurations are sized to fully capture the 5-year DEP storm overflows at each of the tunnel connections. These connections effectively disconnect the sewershed tributary to the connection points from tidal levels. Since the Option 3b and 4b tunnels fully capture flows from the 5-year DEP storm, it effectively makes the OH-007 and RH-034 outfalls and their tributary sewers “resilient” against sea level rise since no CSO would be discharged to the canal under this rainfall event. Option 4b also provides resiliency for the RH-030, RH-031, and RH-035 outfalls along the Bond Lorraine sewer. The resiliency benefit would be seen for any storm event up until the point at which the tunnel is filled.

Phasing and Adaptability Opportunities

One main benefit of tunnels over storage tanks is adaptability. Tunnels could be expanded in the future to serve other drainage areas, and/or increase CSO capture. A summary of potential future construction phases and the associated construction costs is provided on Table 10.

Table 10. Preliminary Parametric Total Project Costs (Not Directly Estimated)

Major Element		Option 4a Tunnel with Flood Reduction Benefits with Bond Lorraine	Option 4b Tunnel with Flood Reduction and Resiliency Benefits with Bond Lorraine	Comments
Gowanus Tunnel Facilities	Mob/Demob	\$ 73,000,000	\$ 78,000,000	
	TDPS & RH-034	\$ 576,000,000	\$ 576,000,000	Possible to Expand TDPS Capacity in Future
	OH-007 Drop Shaft	\$ 319,000,000	\$ 319,000,000	
	Terminal Drop Shaft at RH-031	\$ 244,000,000	\$ 244,000,000	
	Storage Tunnel	\$ 325,000,000	\$ 437,000,000	
	Owls Head Microtunnels	\$ 183,000,000	\$ 183,000,000	Possible to Construct in Future Phase
	Gowanus Facility - Subtotal	\$ 1,730,000,000	\$ 1,840,000,000	
Bond Lorraine Tunnel Facilities	RH-035 Drop Shaft	\$ 170,000,000	\$ 170,000,000	Possible to Construct in Future Phase
	Red Hook Microtunnels	\$ 112,000,000	\$ 112,000,000	Possible to Construct in Future Phase
	Bond Lorraine DWF Pumping Station	\$ 30,000,000	\$ 30,000,000	Possible to Construct in Future Phase
	Interconnection with Gowanus Tunnel	\$ 25,000,000	\$ 25,000,000	Possible to Construct in Future Phase
	Unknowns	\$ 25,000,000	\$ 25,000,000	
	Bond Lorraine - Subtotal	\$ 370,000,000	\$ 370,000,000	
Total		\$ 2,100,000,000	\$ 2,200,000,000	

Schedule Considerations

DEP is advancing parallel designs of the RH-3 and RH-4 CSO tanks consistent with requirements under the Settlement Agreement, which includes milestones for three separate construction contracts for both CSO tanks. CP-1 is a site preparation contract. CP-2 will provide for the Removal Action including the support of excavation and excavation of the tank footprint, as well as construction of the foundation. CP-3 will provide for the superstructure and site improvements. DEP has achieved all Settlement Agreement milestones to-date, and projects compliance with design completion milestones for CP-2 (April 2019) and CP-3 (September 2019) for RH-034. If DEP acquires the

preferred RH-3 site, it will be permitted to cease design of the RH-4 site under the terms of the Settlement Agreement. Acquisition and performance of CP-1 does not accelerate the construction and commissioning of the RH-034 tank, as National Grid is unlikely to be able to advance its obligations at the RH-3 site even if DEP completes its pre-requisite activities early.

The Settlement Agreement currently includes milestone dates (for the RH-034 facility only) for completing CP-1 (demolition and site preparation) and the Removal Action associated with CP-2 (support of excavation and the removal of the soil within the footprint of the tank). Milestone dates for the completion of CP-2 (beyond the Removal Action) and CP-3 (superstructure and mechanical/electrical components) will need to be negotiated as part of a separate order. If EPA concurs with DEP's recommendation to pursue a tunnel program, the Settlement Agreement will need to be modified to reflect the critical milestones for the tunnel program.

Assumptions

The preliminary tunnel evaluation identified technical considerations to be further refined through DEP's facility planning and design process and helped confirm that a tunnel alternative is a viable option for addressing both the requirements in the ROD and other conveyance capacity issues. In order to complete the analysis in the timeframe and budget permitted, certain assumptions have been made. These assumptions will have to be reviewed and updated during subsequent phases of the Gowanus Tunnel evaluation. Key assumptions, include:

- The Tunnel alternative is based on the 5-year DEP storm under full build out conditions. The DEP 5-year storm characteristics were derived under the LTCP program and used as a surrogate for the site-specific storm obtained by applying existing drainage criteria. All tunnel alternatives provide either flooding benefits for the 5-year DEP storm at mean high water (MHW) conditions or resiliency benefits for the 5-year DEP storm at MHW + 58 inches of sea level rise. The InfoWorks model does not incorporate storm attenuation for street storage. Thus, the streets are not being used as storage and the modeling provides the full sewer capacities to safely convey the 5-year storm.
- The InfoWorks model includes all sewers 24-inch diameter or greater but there are a few sections of smaller diameter sewers that have been incorporated into the model. Within the modeled of sewers near to the Gowanus Canal, specific trunk segments were selected for evaluation. Model simulations showed that these sewers benefit by lowering of the hydraulic grade to avoid surcharge. It is assumed that any benefit in these larger trunk sewers will have a corresponding improvement in the smaller local sewers connecting to these trunks. However, there may remain a need to address some existing, smaller diameter sewers using conventional construction methods to replace them with larger sewers.
- The area of analysis for the tunnel alternative was generally bound by Butler Street to the north, 4th Avenue to the east, 12th Street to the south, and the Gowanus Canal to the east. Sewer segments outside of this area were either shown to not have surcharge issues that required hydraulic relief or were considered to be outside the area that could be reasonably intercepted by a tunnel solution near the Gowanus Canal.
- To address flooding concerns along 4th Avenue, the evaluation considered the HGL impacts for locating a drop shaft at the upstream or downstream points along the collector sewers serving 4th Ave. While locating the drop shafts at the upstream side of 4th Avenue provided the greatest reduction in surcharging, the difference (~1-2') was judged to be small in comparison to the drop shafts situated downstream of 4th Avenue. Also, the need to obtain MTA approval to cross under the 4th Avenue subway was eliminated at the downstream locations. The comparable benefits and ease of construction were factors in selecting the downstream locations. Final locations for

connection points will be based on a more detailed impacts evaluation, including coordination with DEP's Bureau of Water and Sewer Operations and other city agencies such as DOT.

- The model was used to assess the impacts to the pre-development sewer capacity with and without an additional 50 % redevelopment scenario along the Canal. The redevelopment zone was based on the "Bridging Gowanus" community listening sessions conducted by NYC Planning. For purposes of the tunnel evaluation synergy analysis, two separate rezoning scenarios were evaluated to determine if the tunnel would provide additional drainage benefits.
 - Scenario 1 assumed 50/50 redevelopment split between residential and manufacturing uses along the Canal from 12th Street to Butler Street and bounded by 4th Avenue to the east and Bond Street to the west.
 - Scenario 2 assumed a 100% redevelopment for residential uses only.

The analysis showed negligible impacts to the existing drainage conditions pre- and post-development.

- The analysis assumes that third siphon crossing at 7th Street has been activated as was incorporated into the IW model. The model also incorporates both phases of the planned high-level storm sewers along Carroll Street (under construction) and Nevins Street (future phase 2) as well as the 9th Street sewer improvements noted above.
- Cost estimates for the tunnel solutions were developed by combining a "bottoms up" estimate of the tunnel, drop shafts, and microtunnel components, with portions of the detailed cost estimate for the tank design. The selected cost elements from the tank design were used to estimate the cost of the PS and superstructure, electrical components, and HVAC/Odor control systems needed for the tunnel infrastructure in the Gowanus neighborhood.

Future Optimization

Although proposed tunnel alternatives incorporate best available information, further analysis is required to confirm conceptual tunnel configurations and optimize facilities. At this point in the evaluation, several facility components may be conservative and require further refinement to develop detailed designs and more accurate cost estimates. Additionally, many features of the tank design were incorporated into tunnel concepts that may require modification for a tunnel system if a tunnel design is advanced. The following items have been identified as requiring further analysis to refine the design of a Gowanus tunnel system:

- Geotechnical investigation to conditions along conceptual tunnel alignments and beneath Gowanus Canal
- Confirmation of tunnel influent flow rates and required storage volume
- Tunnel solids capture performance
- Residuals management strategy and process equipment selections
- Tunnel dewatering rate and discharge location
- Locations of underground utilities at diversion locations and requirements for utility relocation
- Availability of terminal shaft properties and requirements for property acquisition
- Feasibility of Bond-Lorraine tunnel connections and associated diversion flow rate and storage volume requirements
- Feasibility of future construction phases to extend the tunnel
- Hydraulic modeling of diversion structures
- Surge and transient modeling

Since design and construction of several tunnel components can have considerable cost implications and require thorough analysis, conservative assumptions were made for the purposes of developing preliminary cost estimates. Some of these assumptions may be revised as design progresses to reduce the overall project cost. The following items present potential opportunities to reduce the cost of a Gowanus tunnel system:

- Relocation of transformer/network protector equipment outside to reduce building footprints
- Untreated venting of tunnel during wet weather events to reduce the size of odor control facilities
- Elimination of boilers at the RH-3 site superstructure
- Elimination of near-surface screening facilities
- Elimination of tunnel flushing system
- Construction of a single PS at OH-007 in lieu of a new 2nd Avenue PS and separate microtunnel dewatering PS
- Conveyance of flows diverted from 12th Street and 3rd Avenue to the 12th Street terminal shaft instead of OH-007 in Option 3b

Preliminary risks were identified and presented to DEP to inform probable construction schedules and mitigation measures that can be incorporated into design. As the design is advanced and additional information is made available, these risks may increase or decrease, or more risks may be identified. Risks will be continually monitored and evaluated throughout the project. Preliminary risks identified for a Gowanus tunnel are summarized in Table 11.

Table 11. Risk Matrix for Key Programmatic and Construction Risks	
Item	Risks
Third Party	Third Party Approval Delay (private property, NG Barrier Wall, NYCDOT)
Regulatory	Tunnel alternative negotiation with EPA is prolonged
Property Acquisition – OH site	Prolonged Negotiation at OH Site
Property Acquisition – 12th St	Alternate DSNY Garage location falls through
Procurement (Design/Construction)	DEP tunnel alternative decision delay. Current schedule is June 2018.
Permits	Permit Acquisition Delay (SOE, ground improvement borings, SWPPP)
Easements	Alignment Change that requires subsurface easements or land acquisition.
Construction - Shaft	Shaft support structural issues resulting in re-work or partial failure (slurry wall tremie seal break, out-of-tolerance panel, ring beam installation)
Construction - Shaft	Major structural failure of shaft support.
Construction - Protection of Structures	NSS or Shaft excavation results in damage to existing structures
Construction - Protection of Structures	Additional protective mitigations necessary after preconstruction survey of structures. Not anticipated in design. On CP.
Construction - Near Surface Structures	Failure of NSS structure excavation
Construction - Environmental	Hazardous Waste is encountered slowing down work production (tunneling and/or NSS work)
Construction - Commercial	Contractor Default
Construction - Commercial	Contractor claims with Subcontractors delays work
Construction - Tunnel	Tunnel boring machines (TBM) major mechanical breakdown (e.g. cutterhead and screw main bearings, seals, motors, hydraulics, electrics, etc.
Construction - Tunnel	Unanticipated geologic condition impacts TBM tunneling (more rock, more/larger boulders and cobbles)
Construction - Tunnel	Major structural failure of tunnel support.
Construction - Tunnel	TBM is unable to advance and requires emergency rescue shaft (in canal or in 2nd Ave).
Construction - Tunnel	Fire in tunnel during construction resulting in damage to TBM and/or irreparable damage to sections of tunnel lining.
Construction - Tunnel	Flood in tunnel from surface issues at RH site.
Construction - Tunnel	Tunnel excavation results in damage to existing structures
Construction - Microtunnel	Unanticipated geologic condition impacts microtunnelling (more/larger boulders and cobbles, excessive wear)
Construction - Microtunnel	Microtunnel excavation results in damage to existing structures
Construction - Microtunnel	Microtunnel is unable to advance and requires emergency rescue shaft (in canal or in 2nd Ave).
Construction - Microtunnel	Utility Relocation for Microtunnel pit and diversions chambers is late (more utilities than anticipated, utilities company delays, etc.).